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AUTHOR Dunn, Bruce R.; And Others
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ABSTRACT

Electrical brain activity (EEG) was recorded while 13 male and 11 female college students performed a series of recognition and memory tasks. The subjects were right-handed and between 21 and 42 years old. The selected tasks varied in cognitive load from simple recognition of a word flashed on a computer screen to relatively complex serial and word-categorization learning and recall tasks. Topographic Brain Imaging (TBI)--computer generated images of EEG activity across the cerebral cortex of the brain--coupled with discriminate analysis of EEG activity showed clear gender differences in patterns of EEG activity for each of the acquisition tasks. Gender differences were also obtained with the recall data generated from the serial learning task, which indicated that the men recalled significantly more words than did the women. The results are discussed in terms of possible differential strategy use by the sexes during the performance of the tasks. Further, the use of TBI in future cognitive and educational research is explored. Fourteen topographical maps illustrate the cerebral sites at which word detection, single category memory, and serial order memory occur for the male and female subjects. (Author/TJH)

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GENDER DIFFERENCES IN EEG PATTERNS: ARE THEY INDEXES OF DIFFERENT COGNITIVE STYLES?

Bruce R. Dunn
Laboratory for Advanced Studies in Neurocognition
The University of West Florida

Marlin L. Languis and Denise A. Dunn
Brain/Behavior Laboratory
The Ohio State University

David B. Andrews
Keene State College

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Paper presented at the 1988 annual meeting of the American Educational Research Association, New Orleans, Louisiana.

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ABSTRACT

Electrical brain activity (EEG) was recorded while men and women college students performed a series of recognition and memory tasks. The selected tasks varied in cognitive load from simple recognition of a word flashed on a computer screen to relatively complex serial and word-categorization learning and recall tasks. Topographic Brain Imaging (computer generated images of EEG activity across the cerebral cortex of the brain) coupled with discriminate analyses of the EEG data, showed clear gender differences in patterns of EEG activity for each of the acquisition tasks. Gender differences were also obtained with the recall data generated from the serial learning task which indicated that the men recalled significantly more words than did the women. The results were discussed in terms of possible differential strategy use by the sexes during the performance of the tasks. Further, the use of Topographic Brain Imaging in future cognitive and educational research was explored.

GENDER DIFFERENCES IN EEG PATTERNS: ARE THEY INDEXES OF DIFFERENT COGNITIVE STRATEGIES?

There is an accumulating body of evidence indicating that people vary in the way their brains are organized and that this differential organization is related to differences in cognitive style (Dunn, 1985a, 1985b; Languis & Kraft, 1985; Levy, 1980; Reddix & Dunn, 1984). There appear, for example, to be gender differences in the relative maturation rate for the left and right hemispheres for boys and girls, and the inter- and intra-hemispheric brain organization of in adult men and women (see Jere Levy, 1980, and Sandra McGlone, 1980 for extensive reviews).

Several researchers have found that the right hemisphere of boys matures earlier then the right hemisphere of girls especially in terms of processing visuospatial material (e.g., Reid, 1980; Witelson, 1976). Others have found more pronounced left-hemisphere maturation in girls, who in contrast to boys, show a perceptual superiority for verbal material (Bryden, 1970; Kimura, 1967; Reid, 1980).

The literature, however, does not allow us to reach the simple conclusion that females are relatively superior to males in left-hemispheric functioning and that males are superior at those functions attributed to the right-hemisphere. It depends on exactly which right and left-processes are being considered. Levy (1980), for example, argues in her review that rather than

large right- eft differences, males and females differ more in how their respective hemispheres are organized. We tend to agree with Levy although we believe that much of the early literature on which her conclusion was based, is not all that robust.

Today I will report the preliminary results of a study collected at Ohio State's Brain/Behavior Laboratory in collaboration with Marlin Languis, Denise Dunn, David Andrews, and myself which we think are much more indicative of gender differences in EEG patterns than that found in much of the past research literature. We used a well researched index of the brain's electrical response to specific stimulus called the Event Related Potential or ERP and a new technology for demonstrating patterns of EEG called Topographic Brain Imaging.

Topographic Brain Imaging is a relatively new methodology which has been developed to reduce, summarize and display on a computer graphics monitor various features of electrical brain activity from numerous scalp locations.

Insert Figure 1 about here

Further, statistical comparisons of the these condensed data (in our case ERP's) can be made with a control group or condition. The product of this data manipulation is a topographic map of the electrical activity across the entire cerebral cortex (Duffy, Burchfiel, & Lombroso, 1979).

Insert Figure 2 about here

Topographic imaging allows us to see patterns of EEG activity which could typically elude more traditional measures. In other words, differences in patterns should be thought of as the dependent variable.

The Event Related Potential is a specific brain electrical event which is time-locked to the presentation and cognitive processing of a specific stimulus event. In order to distinguish the relatively small ERP from the vast array of electrical activity generated by the brain as it performs its many functions, the stimulus event is shown numerous times while EEG recordings are made. The ERP is obtained by using a signal averaging technique which, theoretically, increases the signal, i. e., the evoked potential, against the random EEG background or noise. Basically, the theory assumes that when the EEG records which were time-locked to the repeated stimulus are averaged together, the background EEG, because of its random nature, will sum to zero, and brain event related to the processing of the stimulus will remain. This is analogous to hearing your name (signal) across a crowded room at a noisy cocktail party (Torello & Duffy, 1985).

Experiment

In the experiment, 13 male and 11 female right-handed college students ranging from 21 to 42 years of age, were given a series of cognitive tasks of varying complexity, ranging from one which required simple perceptual (iconic) processing to more complex categorical and serial learning and recall tasks which required more extensive cognitive processing. EEG was recorded during the simple perceptual task and during the acquisition or learning phase of the learning and recall tasks. Three series of maps representing three of five tasks given to these men and women are described below.

Word Detection

Series 1 maps (Figure 2) show the ERP's produced when the

Insert Figure 2 about here

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subjects' only task was to recognize a word when it flashed on the computer screen and press a counter, i. e., there was little cognitive load. Each subject was shown a total of 31 words.

Several things become apparent when we look at these examples. First (and expected from traditional measures), the range of amplitudes for this "easier" task ranges from 0-13 uv for both sexes. As we will see later, these amplitudes are approximately double those produced by the more difficult

cognitive tasks. Second, the Figure shows that this first big positive wave reached its major peak around the same mean time or latency for men and women (268 vs 264, respectively). This appears to be the P3 or P300 component typically reported in the literature. However, the top map shows the distribution of this positive peaking for males has its prime location in the rear central portion of the brain rather than in the frontal lobes. In contrast, the distribution for females (the bottom map) occurred more symmetrically over a much greater area of the cerebral cortex.

The next series of maps shows a negative peak which occurred

Insert Figure 3 about here.

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on the average at approximately the same time for both males and females (432 ms vs. 428 ms, respectively). These maps show, however, that the distribution for males and females were quite different. Males (top map) tended to produce their greatest mean negativity in the frontal lobes whereas female's (bottom map) greatest negativity occurred in the right posterior areas of the cortex. This negative component occurred in all the tasks reported below and is in the time frame of a negative component discovered by Kutas and Hillyard, (1980a, 1980b, 1980c) when subjects processed semantic anomalies. They termed this negative component the "N400". I will address these similarities later in

this paper.

In order to determine if the apparent differences in our brain maps were "real", a special peak seeking program was used on each subjects ERP data for each of the 21 brain sites. Two windows were "searched" for peaks using a specialized utilities program written for the Brain Atlas III (Miller, Roberts, Pocious & Languis, 1987). After carefully examining a representative sample of each subject's data, the window for the positive or P300 peak was set at 160-300 seconds. The window for the negative peak was set at 300-800 ms.

These peak amplitude data were then subjected to a multivariate discriminant analysis procedure using all 21 brain sites as the "repeated" measure or dependent variable and gender as the categorization factor. Of the 13 male P3 waveforms (across sites) 12 were properly classified as male whereas only 1 was misclassified as female (92%). Of the 11 "P3" peaks produced by women, all 11 were properly classified as female (100%). The negative waveform data had perfect discrimination. All males and all females were properly classified. Interestingly, negative peaks occurred at the same time as in the more complex reading and memory tasks (436 ms) as I will describe in a moment.

The next two tasks subjects were given were based on results and theory from classic verbal learning studies. Based on these early studies, we designed two memory tasks supposedly varying on the amount of cognitive processing or "load" it took to complete

them. Both of these tasks, of course, were considered more difficult that the signal detection (word reading) task discussed earlier.

Category Data

The least difficult of these memory tasks produced the big Series 2 maps shown in Figures 4 & 5. These maps were produced

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Insert Figure 4 about here

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when subjects were given a single 16 word category (either professions or birds) to learn and recall three times. Words were presented in a different order for each of the three trials. At recall, subjects were asked to write down as many of the words as they could remember in any order they wished. Again, EEG was recorded only during the learning phase of the task.

Figure 4 shows that the latency of the positive activity occurs much earlier with this more "difficult" cognitive task for both males and females (184 ms vs 204 ms, respectively) than the previously reported "simple" word detection task (268 ms vs. 264 ms). More importantly, the figure again shows that the distribution of this positive activity is different for males and females. Female's EEG activity tends to occur in the central/parietal areas of the cortex whereas males tend to be more frontal/central.

The next two maps (Figure 5) shows the distribution of

negative activity for males (top map) and females (bottom map).

Insert Figure 5 about here

Again, the distribution of negative peaks appears to be different for the two sexes. The males activity occurs in the left-temporal lobe, the right mid-frontal and the right-occipital lobes. The females in contrast show right frontal, right temporal and bilateral occipital activity. They, like the males, also show some left temporal negative activity although it is not as extensive and ranges from the mid-frontal to the rear-occipital area where it reaches its maximum.

Peak seeking was again performed on each subject's data to find the maximum positive peak in the window of 160 - 300 ms after stimulus presentation. These peak data were then subjected to a mulitivariate discriminant analysis. Of the 78 positive peaks across the 21 brain sites produced by males 62 or 80 % were properly classified as being produced by males. Of the 66 peaks produced by females, 51 or 77 % were properly classified as female. The discriminant analysis of the N400 data produced a greater classification accuracy for females. Of the 78 male records, 62 or 79% were classified as males. Of the 66 female records, 54 or 82% were classified as female.

Serial Order Data

The last series of maps shown in Figures 6 and 7 was

generated by a serial order memory task. Subjects were again given 16 item word lists to learn and recall for three trials with EEG being recorded during the acquisition phase. Lists were shown in the same order for the three trials and subjects were required to learn and recall the list in the order in which the words were presented. Again, this task was supposedly more difficult for subjects that the single category experiment above.

Insert Figure 6 & 7 about here.

Figure 6 indicates that females again have a more symmetrical distribution of their mean early positive P3 data in the frontal/central areas of the brain than males whose mean amplitude is less and is primarily centered in the frontal lobes.

Again, the patterns of negative or "N400" data (Figure 7) between men and women appear to be different with men's pattern showing negative activity primarily in the right hemisphere with the greatest amplitude occurring in the right occipital area of the brain whereas women's occurs bilaterally with the greatest concentration in the occipital areas.

A discriminant analysis was performed on the "P3" peak data from each subject's 6 ERP records. Of the 78 male records, 64 or 76% were properly classified as male. For the 66 female records, 35 or 67% were properly classified as female.

Classification using the negative peak data, was more

accurate than the positive peak data. Of the 84 usable male records, 67 or 80% were properly classified as male. Of the 52 female records, 42 or 81% were properly classified as female.

Recall Data

In order to determine if we had actually varied cognitive load in at least the two memory tasks, the subjects recall data averaged across the three runs were subjected to a 2 (gender) by 2 (task: categorization vs. serial order) mixed ANOVA with repeated measures on the last factor. The analysis yielded significance main effects for sex and task [F (1, 22) = 4.18, p < .054; F (1, 22) = 19.67, p < .0001). Males recalled more words across tasks than females (M = 7.28 vs. M = 6.46, respectively). The main effect of task, suggests that for both sexes, the serial order task was more difficult (M = 9.42) than the categorization task (M = 11.30).

Since the above brain-mapping data only reported gender differences within each task (the data across tasks has not yet been completely analyzed), the recall from each memory task was analyzed separately by a 2-way, gender by trials mixed ANOVA with repeated measures on the trials factor. The ANOVA performed on the category recall data only yielded significance for the trials main effect [F (2, 44) = 89.49, p < .0001] with recall increasing for both sexes as a function of trials (M = 6.54, 11.83, 13.17, respectively). Neither the sex nor the sex by trials interaction reached statistical significance.

When the serial order recall data were analyzed, both the sex and trials main effects were significant [F (1, 22) = 4.42, p < .05; F (2, 44) = 100.76 p < .0001]. Males recalled more on average (10.31) than females (8.36). Not surprisingly, there was an increase in recall as a function of trials (6.54, 9.67, 12.04). More importantly, the sex by trials interaction was significant [F (2, 44) = 5.13, p < .01]. As can be seen in Figure 8, male's mean recall increased more rapidly over trials than did female's (6.84, 10.62, 13.46 vs. 6.18, 8.55, 10.36).

Insert Figure 8 about here

Summary and Conclusions

In summary, our results when seen as a whole, suggest that Topographic Brain Imaging can make distinctions between EEG patterns generated by men and women as they performed tasks varying in cognitive complexity [i.e, word recognition (signal discrimination) and two relatively more complex learning and memory tasks.

When contrasting the data from the single category experiment, one highly interesting finding is that males and females did not differ significantly on total recall data, but did differ on their ERP P3 and N4 component patterns across the cerebral cortex. If these patterns are, in fact, correlated

with cognitive processing, the possibility is raised that males and females may use different parts of their brain to reach the same goal (memorize the words for later recall).

Another possibility, however, also exists. The differential EEG patterns may indicate that different cognitive strategies were used by the two sexes in performing some cognitive tasks. The serial order recall data provide some evidence that this may be the case. As you will recall, males serial order recall increased as a function of learning trials to a much greater extent than females, even though after the first trial, their recall was about the same (6.84 vs. 6.18). This suggests that females either encoded the information using a different strategy during encoding (like making up a story or encoding the information in categories) and at recall lost some of that information as they had to retranslate that information into serial order at recall.

An equally probable explanation is that learning information in serial order may not be a very efficient learning strategy for women. The issue of whether or not different strategies are actually used by males and females will have to wait for further research, since at this juncture either of these possibilities could be argued from our data.

Regardless, the Topographic Maps from this pilot research do reflect differences in cortical activity during cognitive processing related to gender. It is clear to us that with

carefully chosen cognitive tasks coupled with topographic brain imaging, a more clear picture of any "real" differences in the brain organization of men and women can be obtained. Further, since even our more complex tasks were actually simple when compared to school learning, we are quite optimistic that even bigger differences will be found when more educationally related tasks, like solving math and chemistry problems and reading expository prose, are utilized in future investigations.

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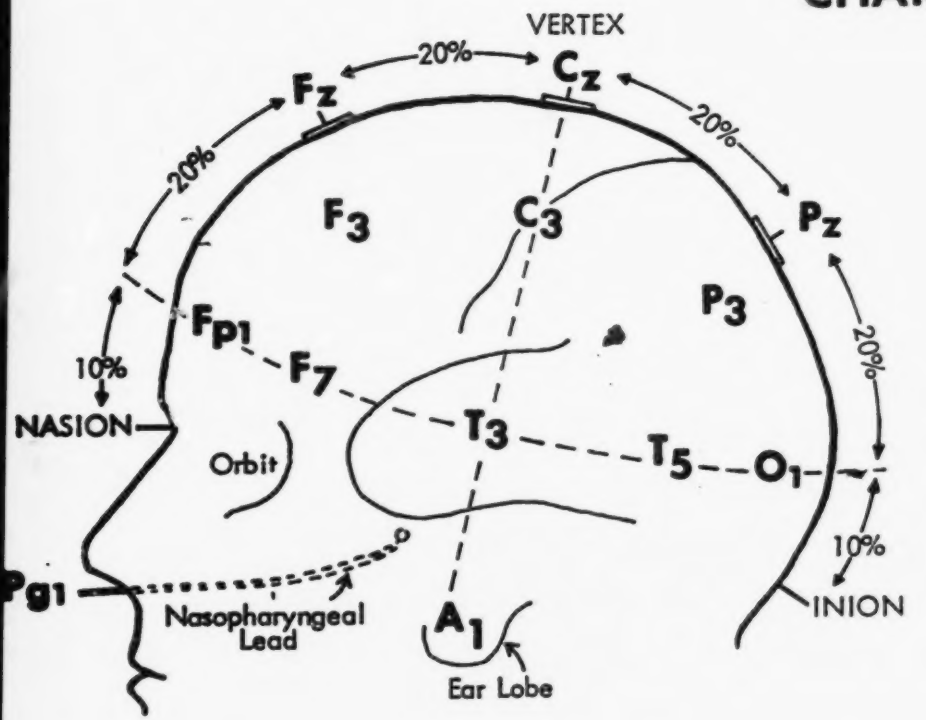
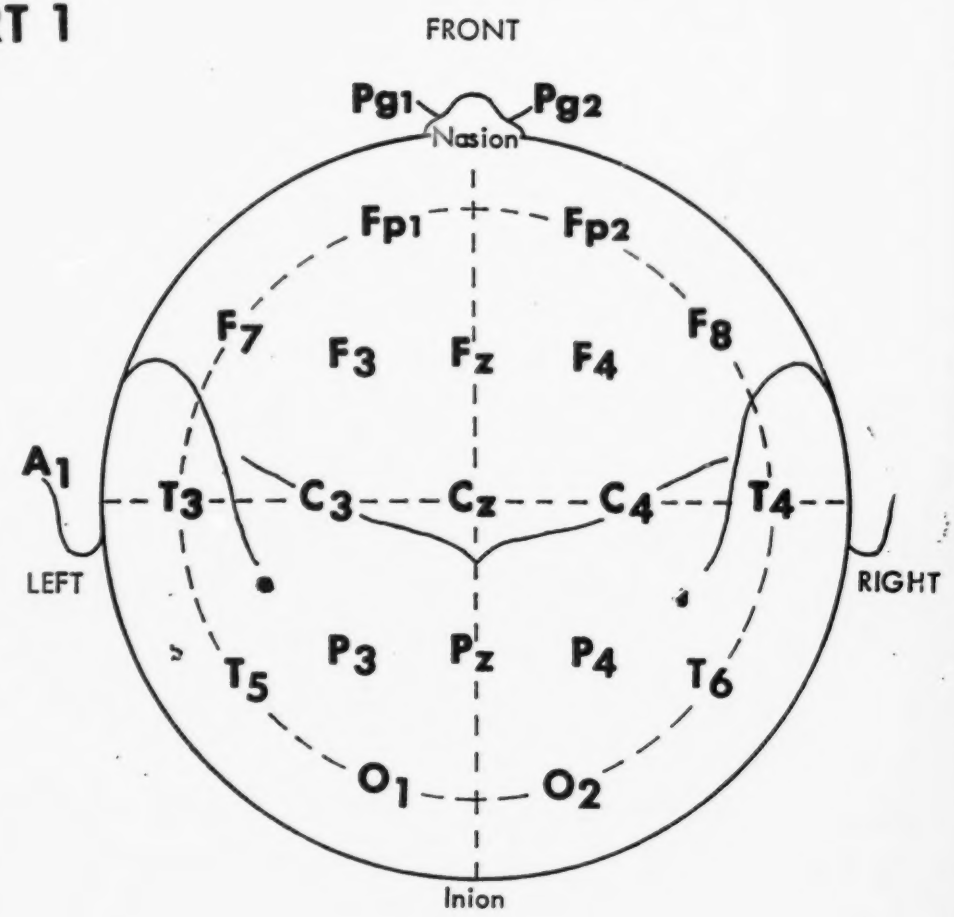
Figure 1. International 10/20 system.

INTERNATIONAL (10-20) ELECTRODE PLACEMENT

CHART 1



LEFT SIDE OF HEAD



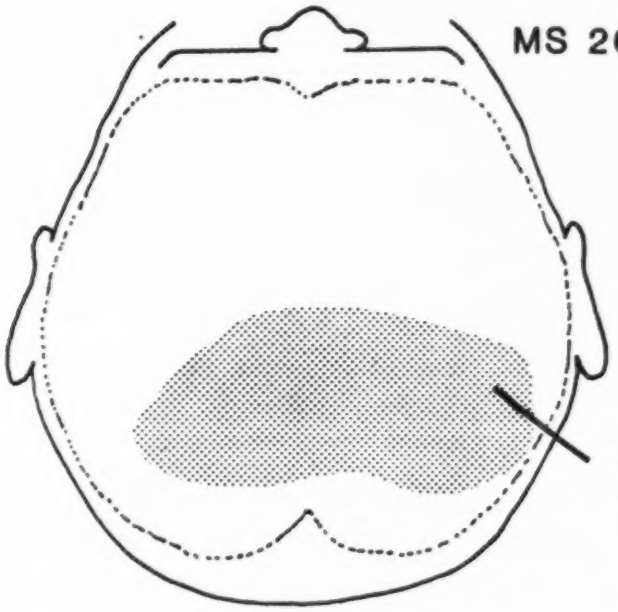
TOP OF HEAD

GRASS MEDICAL INSTRUMENTS SINCE 1935
QUINCY, MASS., U.S.A.

Figure 2. Gender differences in "P3" amplitude during word detection.

WORD DETECTION

MALES



FEMALES

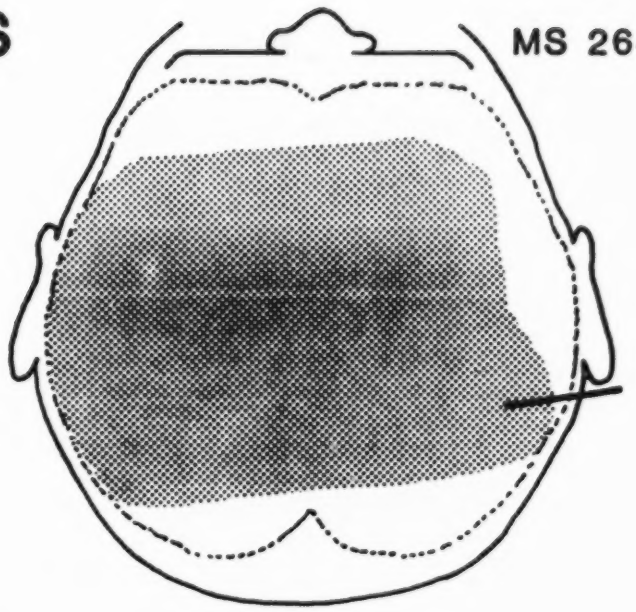
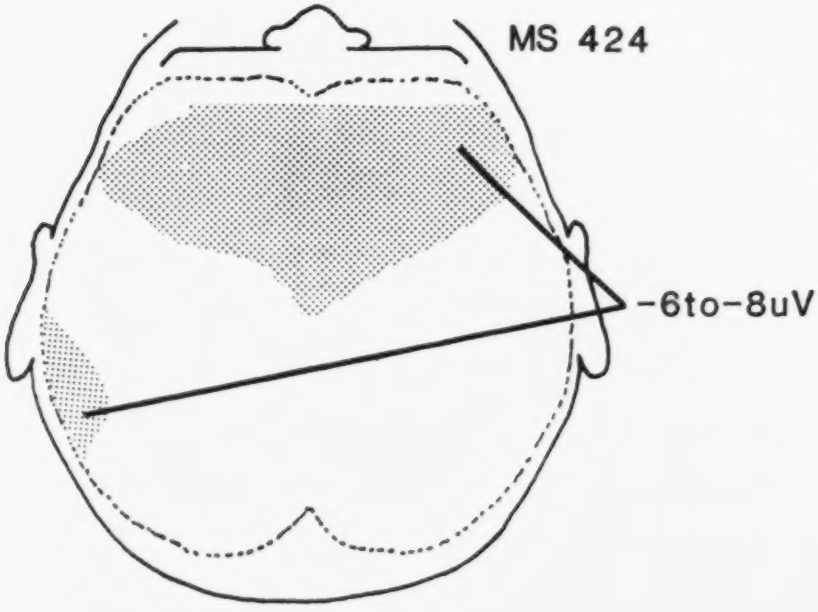


Figure 3. Gender differences in "N4" amplitude during word detection.

WORD DETECTION

MALES



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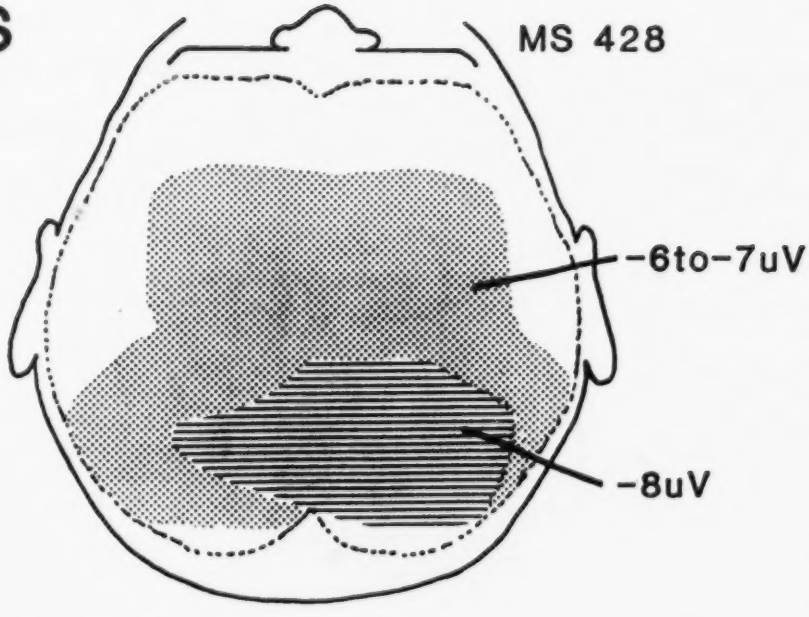
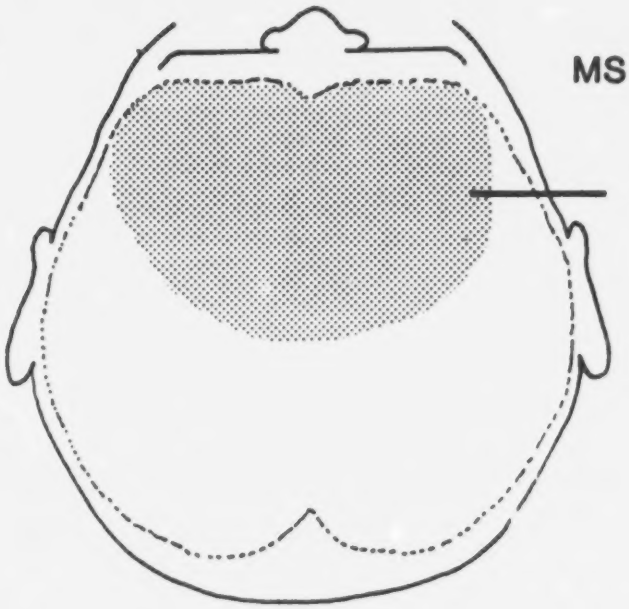


Figure 4. Gender differences in "P3" amplitude during word categorization and recall.

SINGLE CATEGORY MEMORY

MALES



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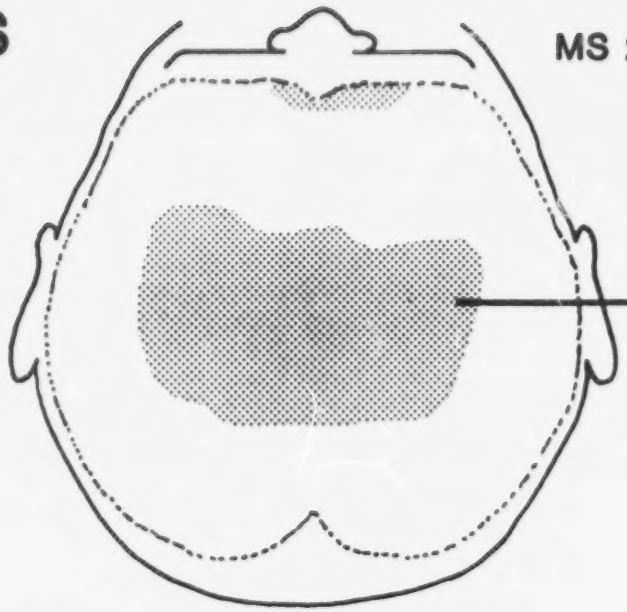
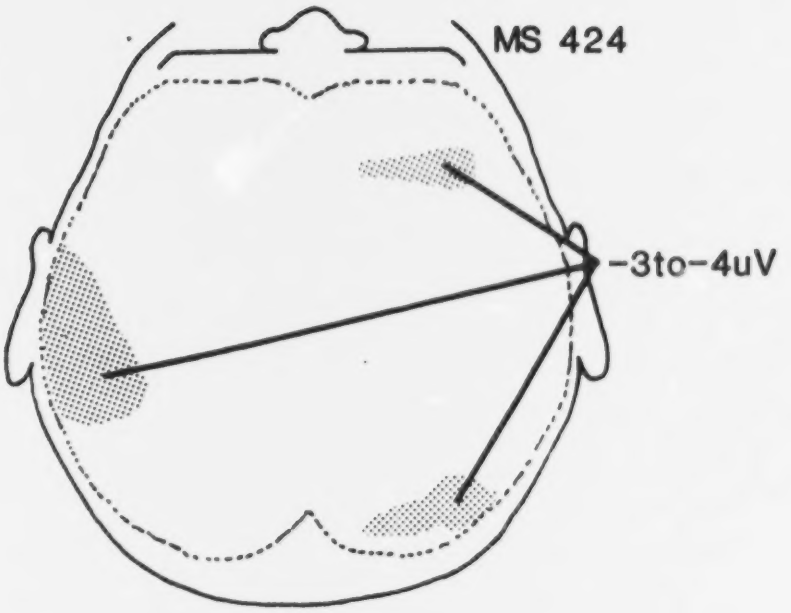


Figure 5. Gender differences in "N4" amplitude during word categorization and recall.

SINGLE CATEGORY MEMORY

MALES



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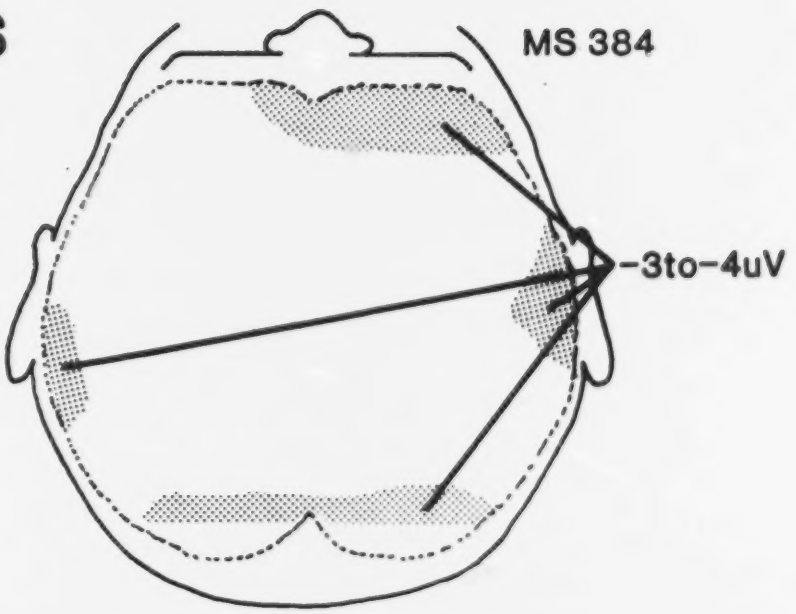
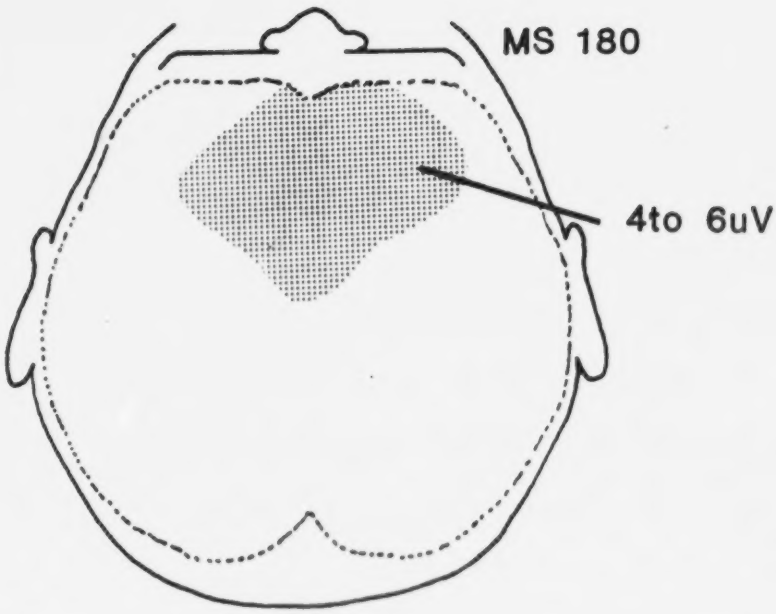


Figure 6. Gender differences in "P3" amplitude during serial learning and recall.

SERIAL ORDER MEMORY

MALES



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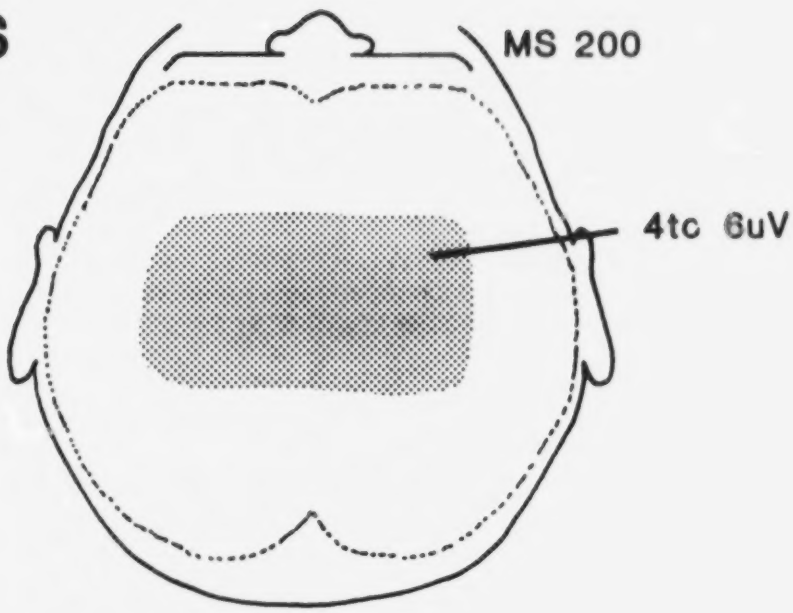
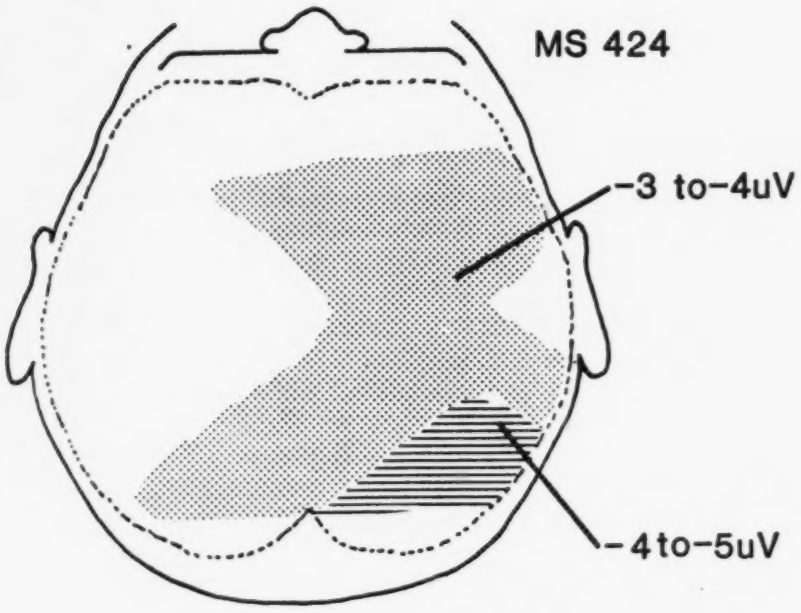


Figure 7. Gender differences in "N4" amplitude during serial learning and recall.

SERIAL ORDER MEMORY

MALES



FEMALES

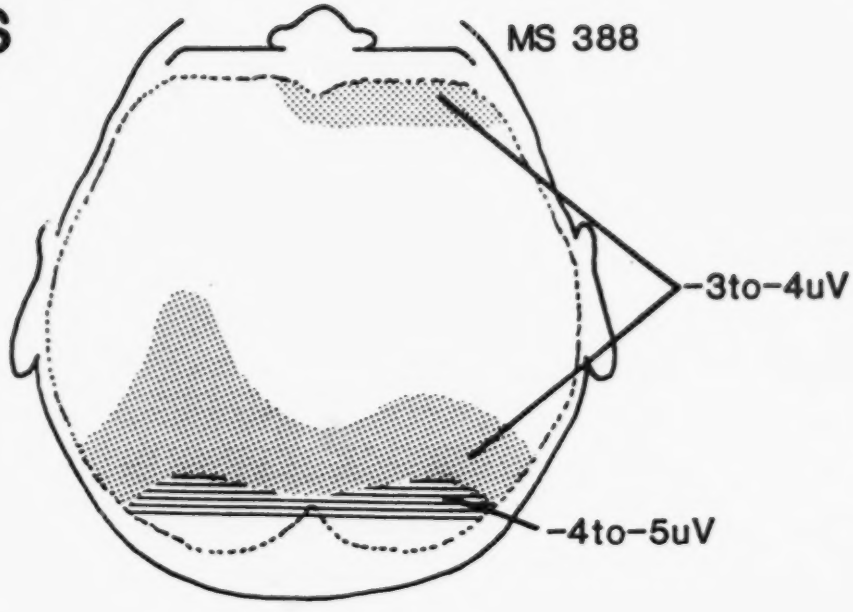


Figure 8. Gender differences in serial word-recall as a function of trials.

GENDER DIFFERENCES IN SERIAL RECALL AS A FUNCTION OF TRIALS

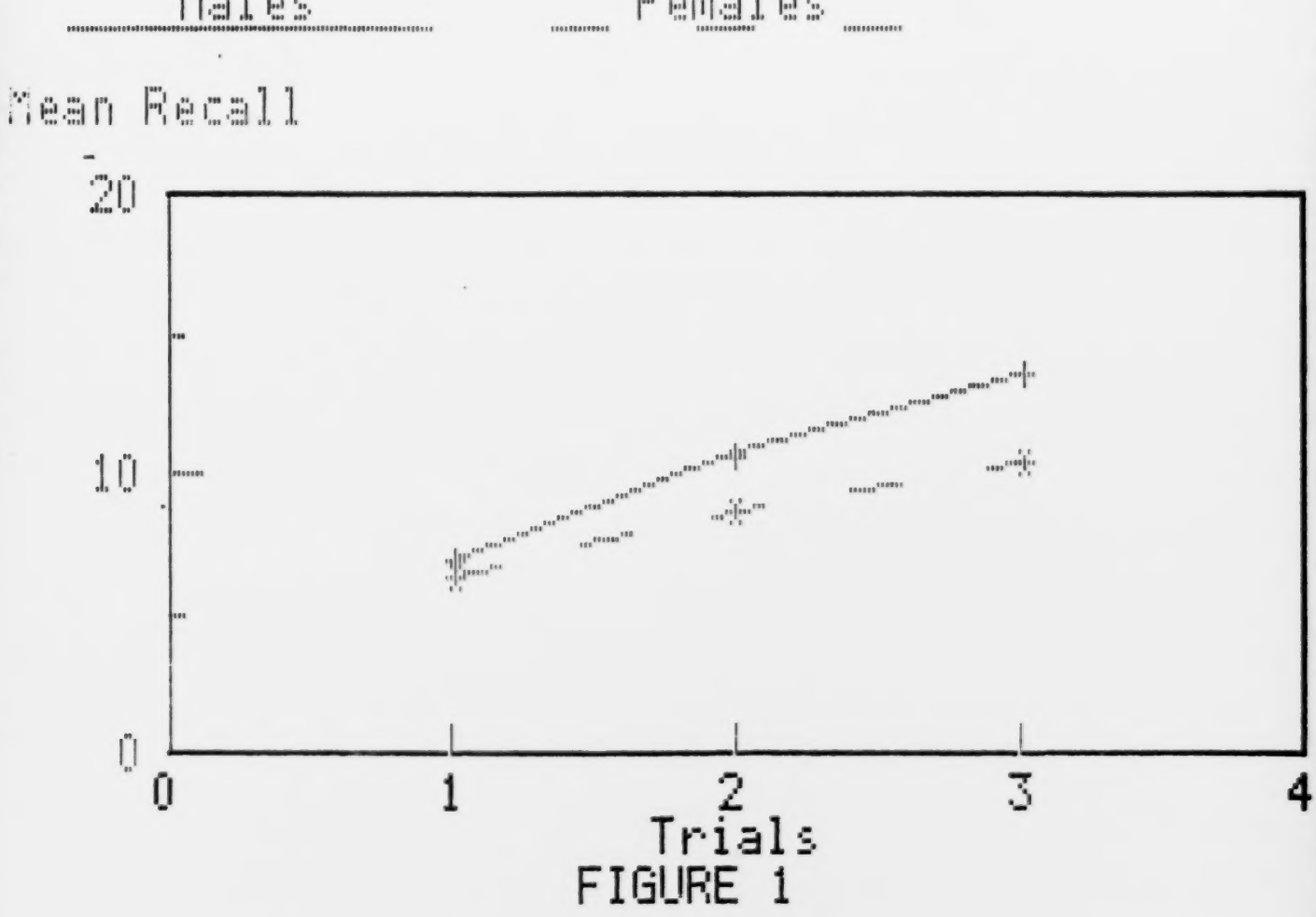


FIGURE 1